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CARA CORPORATION

# The Relation Between Solar Cell Flight Performance Data and Materials and Manufacturing Data

Report No. 5

Fifth Quarterly Report

Contract No. NASW-1732

Prepared by

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# ABSTRACT

The purpose of this contract is to examine the flight performance data for solar cell power systems in satellites, and to try to relate the differences in performance to the materials and manufacturing factors in the solar cell system. In this, the fifth quarterly report, is presented a history covering the selection of the flights for detailed study. The methods of acquiring information concerning these flights are also discussed. A list of the available telemetry data for each flight in the study is also presented, along with the reasons why a flight was, or was not chosen for detailed study. Included in this list are the names of people who are sources of specific information concerning the power subsystems for these vehicles.

In order to develop correlations between the performance and manufacturing data, it was necessary to acquire detailed data on the materials and manufacturing techniques used, as well as for interpretation of the flight performance data. These data were found to be available in principle, but unretrievable in practice. The problem is caused by the nature of the storage mechanisms used for these data.

The attempts made to retrieve the data for the flights chosen for detailed study are described. Opinions are presented as to the reasons why the data could not be obtained and recommendations are made for the future.

Based on the work in this contract, it is recommended that no post flight evaluative studies be supported, unless it is known in advance that the necessary data is available, and in fact readily retrievable.

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## I. Introduction

This document is the fifth quarterly report in a program to examine the flight performance data for solar cell power systems in satellites, and to try to relate the differences in performance to the materials and manufacturing factors in the solar cell system.

The general method of approach consists of selecting a group of flights whose space environments are all similar, for which sufficient flight performance data exists, and for which information on the materials and manufacturing factors is available. For the selected group of flights, an attempt will be made to relate the differences in performance to specific materials or manufacturing parameters that may be expected to affect performance.

The work is divided into four general phases defined by the following outline:

Phase I:

A. Classify all flights from 1957 through 1967 according to their space environment, so that groups of flights with similar environment can be identified

B. Ascertain availability of performance data and materials and manufacturing parameters

C. Generate a coding procedure to facilitate the recording and use of information gathered relative to performance and materials and manufacturing factors.

Phase II:

Select a group of flights based on the work in Phase I.

Phase III:

Acquire and systematize the actual data needed for the flights selected in Phase II.

Phase IV:

Perform analysis to relate materials and manufacturing factors to flight performance of the selected flights.

Phase I and Phase II have been completed and work has progressed through Phase III. It has been determined that the data required for the performance of this contract are contained in documents which do not receive wide distribution. These documents can only be acquired through personal contacts; the flights to be studied and the people associated with them have been organized so that the required information can be obtained.

The final selection of flights for detailed study was made on the basis of available data that was telemetered back concerning the condition of the solar array. The required data for this study has been requested from the appropriate sources, and some of it has been received. The remaining data has been determined to be available in principle, but unavailable in practice. This situation has made Phase IV of this contract, the analysis of the materials and manufacturing parameters and flight performance, impossible within the remaining time and level of effort. The reasons for this conclusion are documented, and recommendations are made for future programs.

Phase IV of this contract, originally allocated to the analysis of the materials and manufacturing techniques and flight performance has been changed, in consultation with the

Technical Monitor, to a systems design for the storage of solar array data. This systems design will be based on the experience and understanding of the type of data required and the nature of the problems involved in acquiring them for post evaluative studies. This systems design should help avoid the problems encountered on this study on future programs.

## II. The Flights Chosen for Study

The initial choice of flights to be studied has been documented in the earlier reports. For completeness, a review of the history of this choice is presented again. An examination of the Space Projects Log from 1957 to 1968 yielded approximately 611 earth satellite flights. By applying the conditions that a suitable flight for study under this contract be (a) in orbit and transmitting data for three months or more, (b) have NASA or DOD as the Project Director, and (c) be unclassified, the number of flights suitable for study were reduced to slightly over 200. These flights were listed in the first quarterly report.

A plot of perigee vs. apogee for these flights showed a number of clusters along the 45° line, suggesting that a rational starting point for selecting flights with similar environments could be chosen by defining four major sets of orbits. I (inside orbit) orbits were defined as having perigee and apogee just inside the first radiation belt. The cutoff point for orbit parameters was arbitrarily chosen to be 760 miles, because above this altitude both electron and proton fluxes increase very rapidly with altitude from negligible to quite significant values. The B (first belt orbit) orbits were defined to be the cluster of flights with perigee and apogee at about 2,000 miles, which is close to the maximum of the first radiation belt. The S (synchronous orbit) orbits, with parameters around 20,000 miles, are the synchronous geostationary flights, and the O (outside orbit) orbits, with orbit parameters between 60,000 and 70,000 miles, are beyond the radiation belts.

The I orbit flights were chosen to be the subject of this study. These flights can be divided into four subgroupings; thirteen flights with angle of inclination between 28° and 33°; sixteen flights with angle of inclination between 47° and 60°; nineteen flights with angle of inclination between 66° and 71°; and twenty-nine flights with angle of inclination between 79° and 135°. The I orbit flights suffer minimal radiation damage since they are below the maxima in the first radiation belt. However, because of the low orbit, the thermal cycle results in appreciable changes in temperature over times measured in minutes. A review of the literature indicated that much more work has been done in examining the radiation effects on solar cells than on any other effect.

The final choice of flights has been based on the availability of flight performance data. If flight data concerning the condition of the solar array is unavailable, then no performance examination can be made. For this reason, the flights chosen for detailed study were those with data transmitted back for the solar array output voltage, array current and array temperature. In many cases, the array temperature and some form of voltage such as the battery voltage was telemetered back. Although this data may be satisfactory for determining in go no-go fashion whether the solar array is functioning, it is inadequate for an analysis of performance degradation.

The vehicles that were finally chosen for study are the Pegasus series, numbers 1, 2 and 3; the OSO series, numbers 1, 2, 3 and 4; OGO 4, and Nimbus 2. There were flights, such as the OV1 series, that did not have a direct measurement of the solar array current, but the battery current was monitored. By knowing the load current, which was known before launch, and the battery current, the solar array current may be calculated. These flights have been discarded, since the indirect current determination multiplied errors and was not satisfactory for our analysis.

The I orbit flights (in the near earth environment) that were examined for possible inclusion in this study are shown in Table I. The reasons for inclusion or rejection of each of these flights are presented in the form of notes to Table I.

All of the flights chosen for detailed study had their solar arrays mounted on panels or paddles, separated from the main body of the spacecraft. It would have been desirable to include flights with body mounted solar arrays, since these two basic and different types of configurations may have vastly different effects caused by temperature fluctuations.

Within the final group of flights selected for detailed study were solar cells produced by a variety of manufactuers. Contained on the Pegasus series were cells from Texas Instruments and Centralab. The OSO series were supplied by Heliotek and Spectrolab. The OGO 4 cells were manufactured by Centralab and the array was fabricated by TRW. Nimbus 2 had cells and arrays fabricated by RCA.

As was pointed out in earlier quarterly reports, there is a sufficiently large variation in environment, even in the near earth orbits, that each flight had to be examined on an individual basis. It was hoped that this effort might have been reduced by subclassifying the vehicles according to type and looking for correlations. However, the number of vehicles was not sufficiently large to allow this approach to be fruitful.

## III. Information and Data Gathering

As was reported earlier, an examination of the published literature was made for acquiring the data required for this study. Two computer search facilities were used to obtain a broad coverage of unclassified reports relating to silicon solar cells in spacecraft. These searches were performed using both NASA and DOD facilities, hoping that all relevant published documents could be obtained in this way. The computer searches included a broad coverage search using "Silicon Solar Cell" as an identifier in both facilities, and a specific search at both facilities in which information was sought on final flight reports, vendor reports on manufacture and testing of solar cell panels and spacecraft power supplies, and flight performance.

In the specific computer search, the names of the NASA and DOD flights in the I, B, S, and O flights were submitted and appropriate identifiers were used with the flight name to perform the search.

When the choice of the I group of flights was made for detailed study, an examination of these documents revealed that with the exception of the Nimbus 2 flight, the published literature did not have sufficient detail for this study. The data required exists in engineering documents and other reports which did not receive wide circulation. To acquire this information, personal contacts were made with individuals associated with each flight.

In order to make these personal contacts, a list of names was generated for people associated with the various flights. The beginning of this list was made by examining the published literature acquired in the computer searches. To supplement this list, which was initially quite sparse as a result of the information obtained through the computer searches, telephone calls were placed to these individuals and requests were made for information for both the flights with which they were associated, and also the names of people associated with other flights in the study. Eventually the list was completed to the point where someone knowledgable of the power sub-system was identified for each flight in the study.

The notes to Table I contain the list of names of people who were sources of information for each of the flights in this study. Table II is a more inclusive list of names of people who were connected in some way with each of these flights. This list should provide a reasonable starting point for anyone trying to seek information about these flights.

In addition to letter and telephone contacts with these people, personal visits were made to personnel at Centralab, Fairchild-Hiller, G.E., GSFC, Heliotek, Lockheed, NRL, OCLI and TRW. In addition to acquiring detailed information on many flights, an understanding was obtained for the entire manufacturing process of solar cells and solar arrays through these visits.

At the end of the previous quarter, some of the data that was required for a detailed analysis of the selected flights was either already obtained, or was promised and should have been acquired within the first few weeks of this past quarter. As it developed, these data were available in principle only, but not in actual practice.

Sufficient data has been acquired for the Nimbus II and OGO 4 flights to conduct a degradation analysis. (Both vehicles have already had degradation analysis performed.) However, it was not possible to acquire the data for the Pegasus and OSO series of flights.

Pegasus 1, 2 and 3 were included in this study. These vehicles were manufactured by Fairchild-Hiller Corporation of Germantown, Maryland. The personnel at Fairchild-Hiller were very helpful to the extent that they were able. (This contract was not structured to pay for any services rendered by personnel in other firms and agencies. Therefore, their time and assistance on this project were given as favors, and was therefore necessarily limited.) At the end of the Pegasus program, its data were placed in dead storage both in Fairchild-Hiller and at the Marshall Space Flight Center in Huntsville, Alabama. Several visits were made to Fairchild-Hiller, and their dead storage for the Pegasus data was made available to us. These data were stored in several hundred cardboard boxes in the basement of one of their facilities in Germantown, Maryland. These data were not indexed or arranged in an organized way. As a result data could not be retrieved in a logical manner. Time was spent actually going through these boxes in a fruitless attempt to retrieve the relevant data. One of the engineers responsible for the solar array power sub-system did have a personal collection of data that gave some general manufacturing data for the solar array and power system.

The same condition was prevelant at M.S.F.C. Invitations were offered by personnel at the M.S.F.C. to spend some time with the people who were concerned with the spacecraft in an effort to reconstruct from memory as much data as possible. These data could not be documented however, and it did not appear possible to determine any attitude data with the corresponding shadow or albedo effect on the solar array output.

The OSO series satellites were manufactured by Ball Bros. Corporation, with the Goddard Space Flight Center as the monitoring agency. The data at Ball Bros. Corporation is reportedly organized so that it can be retrieved in a logical fashion. Apparently, however, this retrieval still required a considerable amount of manpower, and Ball Bros. Corporation was unable to supply this necessary expenditure. They replied that these same data were available through G.S.F.C. and recommended that it be retrieved there. The personnel at G.S.F.C. were anxious to be of assistance, but also were unable to retrieve the data.

The end result is that the manufacturing and analysis data were not obtainable for the Pegasus 1, 2 and 3, and OSO 1, 2, 3 and 4 satellites. These vehicles amounted to seven of the nine vehicles chosen for detailed study. It should be recalled that these nine vehicles (with the exception of the United Kingdom's Ariel III) were the only satellites with sufficient telemetry data for analysis in the total of seventy-seven vehicles chosen on an environmental basis.

The conditions discovered in this study are not unique to a few individual companies or agencies; it is in fact rather common throughout the industry. It is characteristic of all the flights studied that unless a special effort was funded to collect and record data on an organized fashion, it is almost impossible to acquire sufficient data to conduct extensive post flight studies using manufacturing and housekeeping data.

The nature of the projects was to accomplish a primary mission for each vehicle; namely, to conduct scientific experiments. The personnel involved with the vehicle, at the time of the flight, did have sufficient data, or at least a knowledge of its whereabouts to adequately accomplish the primary mission.

These housekeeping data may have existed in the form of rough notes and memory, or factual organized reports at their disposal at the time of the flight of the vehicle. It has not been the purpose of these flights to develop a background of operational data that may be used in post flight studies.

At the end of the project, either nothing was done to preserve the data, or these data, in whatever form they existed, were placed in dead storage. This process appears to have been the simple collection of all notes and documents generated during the program, and the bulk storage of them, such as in cardboard boxes. These data were generally not organized or indexed in any way, so it is almost impossible to retrieve from this storage any accurate and readily available information concerning the flight.

For these reasons, post flight evaluative studies on space vehicles will probably not be successful unless it is known in advance that the data are available and can be readily retrieved. Therefore, post flight evaluation studies are not recommended unless the projects for the vehicles to be studied were designed to organize and store data in such a way as to make them available and retrievable.

The performance data, telemetered back, generally exist on computer tapes, and can be obtained in printout format by direct request to the monitoring agency.

With the performance data that are available for these flights it is not possible to reconstruct the total I-V curve and analyze the degradation with time. If these I-V curves were available, then not only could the amount of degradation be determined, but a strong indication of its causes would also be available. From the data that are available, generally only a small region or single point on the I-V curve can be reconstructed over time. Therefore, in order to make an analysis, it is necessary to develop theoretical I-V curves, and modify them with expected forms of degradation in order to see if a form of degradation can be developed that will match the observed data.

There should be some degradation for each flight due to its radiation environment. This degradation should be predictable, and therefore, the change in I-V characteristics and hence the change in telemetered data should be predictable. If the observed degradation differs vastly from the predicted degradation, then this would be a good starting point for a materials and manufacturing analysis. Variations from expected performance have reportedly been observed for the vehicles selected for detailed analysis in this study.

In making an analysis of the performance of the solar array, it is necessary to know the attitude of the vehicle at the time data is taken. It is not sufficient simply to take "noon-time" data, and expect it to indicate all of the possible types of degradation processes that will occur. Off "noon-time" data are required in order to find some of their processes, such as the partial lifting of cover slides from the solar cells. It is also necessary to know the effects of the earth's albedo and component shadows on the look angle of the solar array with the vehicle's attitude.

Another question that must be considered in analyzing the performance data is the accuracy of the telemetered data. It is necessary to acquire the data which shows the calibration and accuracy of the telemetered data. If the telemetered data are accurate to only 5%, and the degradation amounts to 7 to 10% for one year, then it is very difficult to determine the exact nature of the performance degradation. For these reasons, the data required for interpreting the raw telemetry data are also essential. These data also proved to be unavailable in practice.

It seems possible to circumvent in the future the difficulties encountered in this project by the design of an organized outline, in generic fashion, to serve as a guide for the recording of data for each vehicle. Then, it should not be very costly or difficult for the individual engineers and project managers who are responsible for the various sub-systems in the vehicle, to record the data in an organized way so that it can be retrieved and used at some future date.

As an example of this technique, this study developed and requested the completion of the forms presented in Table III for the solar array sub-system. It appeared to be relatively easy for the engineers and managers connected with the solar array sub-system to complete these forms at the time of the manufacture of the vehicle. Therefore, a system and storage outline can be expanded with these forms as a base. It is also necessary to arrange the physical storage of the data in an organized way, so that the location of the data for the individual sub-systems can be found readily. This process will help preserve the technology and data that were generated for any particular vehicle for future analysis and possible application on other programs.

There are problems to this approach, other than those presented by the mechanics involved in implementing this suggestion. For example, the availability of information must be considered. How will the manufacturers of solar cells (or any other proprietary product) react to supplying information to fill out the generic outlines? What kinds of information will they not supply right now? In the past, if they refused to supply information of a proprietary nature, and it then became non-proprietary due to advances in the state of the art, what mechanisms would they find acceptable for supplying the old information to complete the records?

These problems relating to acquiring the detailed data concerning the manufacture of the solar cells themselves did not occur during this contract. The two current major manufacturers of solar cells, Centralab and Heliotek, were quite open and did disclose their manufacturing techniques to us. However, it must be expected that additional proprietary manufacturing techniques may be developed, as they were for past flights, and the manufacturers of both the solar cells and solar arrays may be hesitant and unwilling in the future to disclose them for storage and possible analysis.

During the next quarter, a system will be designed and recommended for use for the storage of data for solar array power sub-systems in satellites. The use of this proposed system should make future post evaluation studies possible.

## IV. Summary

The purpose of this contract is to examine the flight performance data for solar cell power systems in satellites, and to try to relate the differences in performance to the materials and manufacturing factors in the solar cell system. In this, the fifth quarterly report, is presented a history covering the selection of the flights for detailed study. This selection was based initially on environment, and finally on the basis of available telemetry data. The methods of acquiring information concerning these flights are also discussed. These methods include the development of a list of names of people who had some connections with these flights. A list of the available telemetry data for each flight in the study is also presented, along with the reasons why a flight was, or was not chosen for detailed study. Included in this list are the names of people who are sources of specific information concerning the power sub-systems for these vehicles.

In order to develop correlations between the performance and manufacturing data, it was necessary to acquire detailed data on the materials and manufacturing techniques used, as well as for interpretation of the flight performance data. These data were found to be available in principle, but unretrievable in practice. This is largely due to the nature of the primary mission of the vehicles, namely to conduct scientific experiments, and not to develop a background of operational data that may be used in post flight evaluative studies. The problem is caused by the nature of the storage mechanisms used for these data. These techniques are generally unstructured and therefore unworkable, or at least too unwieldy to readily retrieve the desired information.

The attempts made to retrieve the data for the flights chosen for detailed study are described. Opinions are presented as to the reasons why the data could not be obtained and recommendations are made for the future.

The next quarter will be spent in developing an organized scheme for storing data for the solar array sub-system, so that data on future flights may be readily retrievable for future analysis. Based on the work in this contract, it is recommended that no post flight evaluative studies be supported, unless it is known in advance that the necessary data is available, and in fact readily retrievable.

Table I.

Specific Flights to be Studied

| | Flight Name | Int'l. Desig. | Proj. Dir. | Array Voltage | Array Current | Array Temp. | Notes | No Solar Array |
|---|---|---|---|---|---|---|---|---|
| 1. | Pegasus 3 | 1965 60A | NASA | X | X | X | 1 | |
| 2. | Pegasus 1 | 1965 9A | NASA | X | X | X | 1 | |
| 3. | Pegasus 2 | 1965 39A | NASA | X | X | X | 1 | |
| 4. | Transit 4B | 1961 AH1 | USN | | | | 2 | |
| 5. | TRAAC | 1961 AH2 | USN | | | | 2 | |
| 6. | OSO 1 | 1962 Z1 | NASA | X | X | X | 3 | |
| 7. | OV4 3 | 1966 99A | USAF | | | | 4 | X |
| 8. | OV4 1R | 1966 99B | USAF | | | | 5 | X |
| 9. | OV4 1T | 1966 99D | USAF | | | | 5 | X |
| 10. | OSO 2 | 1965 7A | NASA | X | X | X | 3 | |
| 11. | OSO 3 | 1967 20A | NASA | X | X | X | 3 | |
| 12. | TTS 1 | 1967 123B | NASA | X | | X | 6 | |
| 13. | OSO 4 | 1967 100A | NASA | X | X | X | 3 | |
| 14. | Tiros 3 | 1961 P1 | NASA | X | | X | 7 | |
| 15. | Tiros 4 | 1962 B1 | NASA | X | | X | 7 | |
| 16. | Tiros 1 | 1960 B2 | NASA | X | | X | 7 | |
| 17. | Tiros 2 | 1960 II-1 | NASA | X | | X | 7 | |
| 18. | Anna 1B | 1962 BM1 | USN | | | | 2 | |
| 19. | Explorer 7 | 1959 I-1 | NASA | | | | 8 | |
| 20. | Transit 1B | 1960 Γ2 | ARPA | | | | 2 | |
| 21. | Explorer 23 | 1964 74A | NASA | | | | 2 | |
| 22. | Explorer 16 | 1962 BX1 | NASA | | | | 8 | |
| 23. | Ariel 1 | 1962 01 | NASA/UK | | | | 9 | |
| 24. | Explorer 17 | 1963 9A | NASA | | | | 10 | X |
| 25. | Tiros 5 | 1962 AA1 | NASA | X | | X | 7 | |

Table I. Cont.

Specific Flights to be Studied

| | Flight Name | Int'l. Desig. | Proj. Dir. | Array Voltage | Array Current | Array Temp. | Notes | No Solar Array |
|---|---|---|---|---|---|---|---|---|
| 26. | Tiros 6 | 1962 AΨ1 | NASA | X | | X | 7 | |
| 27. | Tiros 7 | 1963 24A | NASA | X | | X | 7 | |
| 28. | Tiros 8 | 1963 54A | NASA | X | | X | 7 | |
| 29. | Explorer 30 | 1965 93A | USN/NASA | | | X | 11 | |
| 30. | Transit 2A | 1960 H1 | USN | | | | 2 | |
| 31. | Solrad 1 | 1960 H2 | USN | | | X | 11 | |
| 32. | Transit 4A | 1961 01 | USN | | | | 2 | |
| 33. | Injun 1/ Solrad 3 | 1961 02 | USN | | | X | 11 | |
| 34. | Solrad 7A | 1964 1D | USN/USA | | | X | 11 | |
| 35. | Secor 1 | 1964 1C | USN/USA | | | X | 12 | |
| 36. | GGSE 1 | 1964 1B | USN/USA | | | X | 11 | |
| 37. | Surcal | 1967 53B | USAF/USN | | | X | 11 | |
| 38. | Surcal | 1967 53F | USAF/USN | | | X | 11 | |
| 39. | GGSE 4 | 1967 53C | USAF/USN | | | X | 11 | |
| 40. | GGSE 5 | 1967 53D | USAF/USN | | | X | 11 | |
| 41. | Surcal | 1967 53J | USAF/USN | | | X | 11 | |
| 42. | GGSE 2 | 1965 16B | USN/USA/ USAF | | | X | 11 | |
| 43. | GGSE 3 | 1965 16C | USN/USA/ USAF | | | X | 11 | |
| 44. | Solrad 7B | 1965 16D | USN/USA USAF | | | X | 11 | |
| 45. | Secor 3 | 1965 16E | USN/USA/ USAF | | | X | 12 | |

Table I. Cont.

Specific Flights to be Studied

| | Flight Name | Int'l. Desig. | Proj. Dir. | Array Voltage | Array Current | Array Temp. | Notes | No Solar Array |
|---|---|---|---|---|---|---|---|---|
| 46. | Oscar 3 | 1965 16F | USN/USA/ USAF | | | X | 13 | |
| 47. | Surcal | 1965 16G | USN/USA/ USAF | | | X | 11 | |
| 48. | Surcal | 1965 16H | USN/USA/ USAF | | | X | 11 | |
| 49. | Explorer 22 | 1965 64A | NASA | | | | 2 | |
| 50. | Explorer 20 | 1964 51A | NASA | | | | 8 | |
| 51. | Ariel 3 | 1967 42A | UK | | | | 14 | |
| 52. | Discoverer 20 | 1961 E1 | USAF | | | | 15 | X |
| 53. | Discoverer 21 | 1961 Z1 | USAF | | | | 15 | X |
| 54. | Discoverer 18 | 1960 Σ1 | USAF | | | | 15 | X |
| 55. | Discoverer 36 | 1961 AK1 | USAF | | | | 15 | X |
| 56. | None | 1962 Σ1 | USAF | | | | 16 | |
| 57. | OGO 4 | 1967 73A | NASA | X | X | X | 17 | |
| 58. | None | 1963 38C | USN | | | | 2 | |
| 59. | Secor 2 | 1965 17B | USA | | | X | 12 | |
| 60. | None | 1964 83C | USAF/USN | | | | 2 | |
| 61. | None | 1964 83D | USAF/USN | | | | 2 | |
| 62. | Surcal | 1965 65B | USN | | | X | 11 | |
| 63. | Surcal | 1965 65C | USN | | | X | 11 | |
| 64. | Surcal | 1965 65E | USN | | | X | 11 | |
| 65. | Surcal | 1965 65F | USN | | | X | 11 | |
| 66. | Surcal | 1965 65H | USN | | | X | 11 | |
| 67. | Surcal | 1965 65L | USN | | | X | 11 | |

Table I. Cont.

Specific Flights to be Studied

| | Flight Name | Int'l. Desig. | Proj. Dir. | Array Voltage | Array Current | Array Temp. | Notes | No Solar Array |
|---|---|---|---|---|---|---|---|---|
| 68. | None | 1963 22A | USAF/USN | | | | 2 | |
| 69. | OV1-10 | 1966 111B | USAF | X | | X | 18 | X |
| 70. | Samos 2 | 1961 A1 | USAF | | | | 15 | X |
| 71. | ESSA 1 | 1966 8A | ESSA | X | | X | 7 | |
| 72. | Nimbus 2 | 1966 40A | NASA | X | X | X | 19 | |
| 73. | OV1-12 | 1967 72D | USAF | X | | X | 18 | |
| 74. | OV1-86 | 1967 72A | USAF | X | | X | 18 | |
| 75. | None | 1964 48A | USAF | | | | 16 | |
| 76. | OV1-4 | 1966 25A | USAF | X | | X | 18 | |
| 77. | OV1-5 | 1966 25B | USAF | X | | X | 18 | |

Notes to Table I

1. The Pegasus series, flights 1, 2 and 3, do have sufficient data telemetered back to establish a performance analysis. These vehicles were manufactured by Fairchild-Hiller. Information can be obtained from:

   Mr. Richard Julius
   S&J Industries
   6009 Farrington Avenue
   Alexandria, Virginia 22304

   Mr. James Mott
   Fairchild-Hiller Corporation
   Fairchild Drive
   Germantown, Maryland

2. These are APL flights for which the data cannot be located. Information can be obtained from:

   Mr. Wade Radford
   Mr. W. E. Allen
   Applied Physics Laboratory
   The Johns Hopkins University
   8621 Georgia Avenue
   Silver Spring, Maryland 20910

3. The OSO series of satellites do have sufficient data telemetered back to make a performance analysis of the solar arrays. Information can be obtained from:

   Mr. Hal Manzenti
   Mr. Bruce Thompson
   Ball Brothers Research Corporation
   Boulder, Colorado 80302

   Mr. John Thole
   GSFC
   Greenbelt, Maryland

4. OV4 did not have any solar array. Information can be obtained from:

   Mr. Robert Demoret
   Martin Company
   Denver, Colorado

5. OV4 1R and OV4 1T did not have solar arrays. Information can be obtained from:

   Mr. J. I. Barker
   Avionics Laboratory
   Wright-Patterson Air Force Base, Ohio

6. TTS 1 had data telemetered back, but the scatter was too large to observe performance degradation, therefore, this vehicle is not being studied. Information can be obtained from:

   Mr. Frank Kelly
   Office M2/1145
   TRW Systems Group
   One Space Park
   Redondo Beach, California 90278

7. The Tiros series of vehicles had no current data telemetered back regarding the condition of the solar array. Information can be obtained from:

   Mr. Robert Rados
   GSFC
   Greenbelt, Maryland

   Mr. Abe Schnapf
   Astro Electronics Division
   Radio Corporation of America
   Heightstown, New Jersey

8. Explorer flight 16 monitored battery voltage only. Explorer flights number 7 and 20 are two flights for which the availability of flight data is not yet known. Information can be obtained from:

   Mr. Frank Martin
   Mr. Herman Lagow (Explorer 7)
   Mr. E. D. Nelson (Explorer 20)
   GSFC
   Greenbelt, Maryland

   Mr. Earl Hastings, Jr. (Explorer 16)
   Mr. Walter E. Ellis (Explorer 16)
   Langley Research Center
   Hampton, Virginia

9. There was no flight data telemetered back regarding the solar array on this vehicle. Information can be obtained from:

   Mr. Luther Slifer
   GSFC
   Greenbelt, Maryland

10. Explorer 17 has no solar array. Information can be obtained from:

    Mr. Frank Martin
    GSFC
    Greenbelt, Maryland

11. These vehicles did not have any current data or array voltage telemetered back. They had the array temperature, and battery voltage telemetered back. Information can be obtained from:

    Mr. Peter Wilhelm
    Mr. Joseph Yuen
    NRL
    Washington, D. C.

12. Secor 1, 2 and 3 had only the battery voltage and solar array temperature data telemetered back. Information can be obtained from:

Mr. George Sharman
Cubic Corporation
9233 Balboa Avenue
San Diego, California

Mr. E. Cyran
U.S. Army Map Service
6500 Brooks Lane
Washington, D. C. 20315

13. Oscar 3 is a satellite built by the American Radio Relay Link. This vehicle was built by a group of amateur radio operators, and had the battery voltage and temperature, but no solar array current data telemetered back. Information can be obtained from:

Mr. William Dunkerly
American Radio Relay Link
Millington, Connecticut

14. This vehicle has extensive data published on it. But it was built in the United Kingdom, and the degree of difficulty of acquiring data is anticipated to be too great to include it in the study. Information can be obtained through the people listed in Table II.

15. Discoverer flights number 18, 20, 21, and 36 and Samos 2 did not have solar arrays. Information can be obtained from:

Mr. L. Chidester
Box 504
Building 154, Dept. 6225
Lockheed Missile and Spacecraft Company
Sunnyvale, California

16. For vehicles None 1962 Sigma 1 and None 1964 48A, no data could be found at SAMSO. The suggestion was made to search Lockheed for the data required. Information at SAMSO was obtained through:

Major General L. I. Wilson, Jr.
SAMSO
LO OAR
Air Force Unit Post Office
Los Angeles, California 90045

17. OGO 4 has sufficient flight data available for a performance analysis of the solar arrays. Information can be obtained from:

Mr. Robert Beltz
Office M2/2170
TRW Systems Group
One Space Park
Redondo Beach, California 90278

18. The OV1 series does not have any direct measurement of solar array current, but the battery current is monitored. By knowing the load current, the solar array current can be calculated. Information can be obtained from:

Major James McSherry
Lt. Col. Robert S. Slizeski
SAMSO
LO OAR
Air Force Unit Post Office
Los Angeles, California 90045

Mr. Bruce Zillgitt
Department 506-10
General Dynamics Corporation
Convair Division
P. O. Box 1128
San Diego, California 92112

19. Nimbus 2 has sufficient data telemetered back regarding the solar array for a performance analysis and extensive documentation is available on the vehicle itself. Information can be obtained from:

Mr. C. McKenzie
GSFC
Greenbelt, Maryland

Mr. K. F. Martin
Mr. K. L. Hanson
Missile and Space Division
Valley Forge Space Technology Center
General Electric
P. O. Box 8555
Philadelphia, Pennsylvania 19101

Table II

Specific Flights with Individual Contact

| Flight Name | International Designation | Sponsoring Agency | Individual Contact | Contact Affiliation |
|---|---|---|---|---|
| Anna 1B | 1962 BM1 | USN | R.E. Fischell | APL |
| | | | J.H. Martin | |
| | | | W.E. Radford | |
| | | | W.E. Allen | |
| | | | J.H. Martin | Heliotek |
| | | | J.S. Teener | |
| | | | E.L. Ralph | |
| Ariel 1 | 1962 01 | NASA/UK | L. Slifer | GSFC |
| Ariel 3 | 1967 42A | UK | R.B. Bent | S.R.C. Radio & Space Research Station Slough, England |
| | | | F.C. Trebel | Royal Aircraft Establishment |
| | | | R.C. Cook | |
| | | | P.G. Garratt | |
| Discoverer 18 | 1960 Σ1 | USAF | L. Chidester | Lockheed |
| Discoverer 20 | 1961 E1 | USAF | L. Chidester | Lockheed |
| Discoverer 21 | 1961 Z1 | USAF | L. Chidester | Lockheed |
| Discoverer 36 | 1961 AK1 | USAF | L. Chidester | Lockheed |
| ESSA | 1966 8A | ESSA | A. Schnapf | RCA |
| | | | R. Rados | GSFC |
| Explorer 7 | 1959 I-1 | NASA | J. Boehm | MSFC |
| | | | Herman Lagow | MSFC |
| Explorer 16 | 1962 BX1 | NASA | F. Martin | GSFC |
| | | | Earl Hastings, Jr. | |
| | | | Walter E. Ellis | |
| Explorer 17 | 1963 9A | NASA | F. Martin | GSFC |
| Explorer 20 | 1964 51A | NASA | E.D. Nelson | GSFC |
| Explorer 22 | 1965 64A | NASA | W. Allen | APL |
| Explorer 23 | 1964 74A | NASA | F. Martin | GSFC |
| Explorer 30 | 1965 93A | USN/NASA | F. Martin | GSFC |

Table II (Cont.)

Specific Flights with Individual Contact

| Flight Name | International Designation | Sponsoring Agency | Individual Contact | Contact Affiliation |
|---|---|---|---|---|
| GGSE 1 | 1964 1B | USN/USA | P. Wilhelm | NRL |
| GGSE 2 | 1965 16B | USN/USA/USAF | J. Yuen | NRL |
| GGSE 3 | 1965 16C | USN/USA/USAF | " | " |
| GGSE 4 | 1967 53C | USAF/USN | " | " |
| GGSE 5 | 1967 53D | USAF/USN | " | " |
| Nimbus 2 | 1966 40A | NASA | K.F. Merten | G.E. |
| | | | K.L. Hanson | |
| | | | W.J. Schlotter | |
| | | | H. Press | GSFC |
| | | | C. McKenzie | |
| None | 1963 38C | USN | R.F. Fischell | APL |
| None | 1964 83C | USAF/USN | J.H. Martin | |
| | | | W.E. Radford | |
| | | | W.E. Allen | |
| None | 1962 Σ1 | USAF | | |
| None | 1963 22A | USAF/USN | R.F. Fischell | APL |
| None | 1964 48A | USAF | | |
| None | 1964 83D | USAF/USN | R.F. Fischell | APL |
| OGO 4 | 1967 73A | NASA | H. Montgomery | GSFC |
| | | | F.B. Shaffer | |
| | | | J. Callaghan | |
| | | | G.J. Gleghorn | TRW |
| | | | A. Krausy | |
| | | | R.L. Robinson | |
| | | | R.B. Beltz | |
| | | | H.G. Mesch | |
| | | | A.C. Lee | |
| Oscar 3 | 1965 16F | USN/USA/ USAF | W. Dunkerly | ARRL |

Table II (Cont.)

Specific Flights with Individual Contact

| Flight Name | International Designation | Sponsoring Agency | Individual Contact | Contact Affiliation |
|---|---|---|---|---|
| OSO 1 | 1962 Z1 | NASA | J. Thole | GSFC |
| OSO 2 | 1965 7A | NASA | W. Gallagher | " |
| OSO 3 | 1967 20A | NASA | W. Downs | Ball Bros. Corp. |
| OSO 4 | 1967 100A | NASA | H. Manzenti | " |
| | | | B. Thompson | " |
| OV4 3 | 1966 99A | USAF | R. Dermoret | Martin Company |
| OV4 1R | 1966 99B | USAF | J.I. Barker | WPAFB |
| OV4 1T | 1966 99D | USAF | J.I. Barker | WPAFB |
| OV1 4 | 1966 25A | USAF | L. Otten | General Dynamics |
| OV1 5 | 1966 25B | USAF | B. Zillgitt | " |
| OV1 10 | 1966 111B | USAF | J. McSherry | SAMSO |
| OV1 12 | 1967 72D | USAF | R. Slizeski | " |
| OV1 86 | 1967 72A | USAF | " | " |
| Pegasus 1 | 1965 9A | NASA | J. Mott | Fairchild-Hiller |
| | | | G. Graff | Fairchild-Hiller |
| Pegasus 2 | 1965 39A | NASA | R. Julius | S&J Industries |
| Pegasus 3 | 1965 60A | NASA | " | " |
| Samos 2 | 1961 A1 | USAF | F. Ackerman | Lockheed |
| | | | L. Chidester | Lockheed |
| Secor 1 | 1964 1C | USN/USA | G. Sharman | Cubic Corp. |
| Secor 2 | 1965 17B | USA | E. Cyran | U.S.A. Map Service |
| Secor 3 | 1965 16E | USAF/ USN/USA | " | " |
| Solrad 1 | 1960 H2 | USN | P. Wilhelm | NRL |
| Injun/ Solrad 3 | 1961 02 | USN | G. Peiper | NASA |
| Solrad 7A | 1964 1D | USN/USA | P. Wilhelm | NRL |
| | | | J. Yuen | NRL |
| Solrad 7B | 1965 16D | USAF/ USN/USA | " | " |

Table II (Cont.)

Specific Flights with Individual Contact

| Flight Name | International Designation | Sponsoring Agency | Individual Contact | Contact Affiliation |
|---|---|---|---|---|
| Surcal | 1965 16G | USAF/ USN/USA | " | " |
| Surcal | 1965 16H | USAF/ USN/USA | J. Yuen | NRL |
| Surcal | 1965 65B | USN | P. Wilhelm | NRL |
| Surcal | 1965 65C | USN | " | " |
| Surcal | 1965 65E | USN | " | " |
| Surcal | 1965 65F | USN | " | " |
| Surcal | 1965 65H | USN | " | " |
| Surcal | 1965 65L | USN | " | " |
| Surcal | 1967 53B | USAF/USN | " | " |
| Surcal | 1967 53F | USAF/USN | " | " |
| Surcal | 1967 53J | USAF/USN | " | " |
| Tiros 1 | 1960 B2 | NASA | R. Rados | GSFC |
| Tiros 2 | 1960 II-1 | NASA | W.G. Stroud | |
| Tiros 3 | 1961 P1 | NASA | E. Cortright | |
| Tiros 4 | 1962 B1 | NASA | J. Maskasky | |
| Tiros 5 | 1962 AA1 | NASA | A. Schnapf | RCA |
| Tiros 6 | 1962 A$\psi$1 | NASA | R. Scott | RCA |
| Tiros 7 | 1963 24A | NASA | " | " |
| Tiros 8 | 1963 54A | NASA | " | " |
| Tiros 10 | 1965 51A | NASA | " | " |
| TRAAC | 1961 AH2 | USN | R.E. Fischell | APL |
| | | | W. Allen | " |
| Transit 1B | 1960 Γ2 | ARPA | R.E. Fischell | APL |
| Transit 2B | 1960 H1 | USN | W.C. Scott | APL |
| Transit 4A | 1961 01 | USN | W. Allen | " |
| Transit 4B | 1961 AH1 | USN | " | " |
| TTS 1 | 1967 123B | NASA | P. Burr | GSFC |
| | | | R. Kelly | TRW |

## Table III

## Outline for Recording Pertinent Solar Cell Data

CARA Flight Number

Satellite Name | International Designation

Sponsoring Agency

Prime Contractor | Contract Number

Solar Cell Manufacturer | Contract Number

### Orbit Data

Launch Date:
Site:
Vehicle:

Perigee $\theta$:
Apogee: T:

### Solar Cell Data

Type:
Dimension:
Resistivity:
Efficiency:
Spectral Response:

### Base Material

Type:
Thickness:
Purity:
Method of Preparation:

Dopant

- Type
  Diffusion Depth
  Concentration

Cover Slide

Material
Thickness
Transmission
Vendor

Cover Slide Adhesive

Name & Vendor
Thickness
Transmission
Preparation
Application
Cure

Cover Slide Coating

Type
Thickness
Transmission & Spectral Response
Application Technique

Front Surface Conductor

Type
Material
Resistivity
Thickness
Application Technique

"Finger" Conductors

Type
Material
Resistivity
Thickness
Dimensions
Application Technique

Solder Contact

Material
Thickness
Resistivity
Application Technique

Solar Cell Module

Dimensions
Number of Cells
Type of Overlays
Description of Exposed Area

Interconnections

Wiring Diagram
Material
Processing Technique

Panel

Size
Deployment Technique
Location on Spacecraft
Module Interconnection Details

Preflight Test Details

Mechanical
Performance
Voc
Isc
Vacuum-thermal
Illumination

Flight Details

Orientation
Stabilization
Unusual Phenomena

Environmental Factors

Thermal Cycling of Panel (frequency, amplitude)
Radiation and Particle Environment
- Electron
- Proton
- Micrometer

Performance Details

I-V Characteristics as a Function of Time

| | | |
|---|---|---|
| Voc | Vs. | Time |
| Isc | " | " |
| Fill Factor | " | " |
| Maximum Power | " | " |